XVII.—*On some Experiments instituted to supply* all *the Lines terminating at the Calcutta Telegraph Office with Currents tapped from the Main-Current produced by a Dynamo-electric Machine.** —*By* Louis Schwendler, M. Inst. C. E.

Introduction.—On the 5th November 1879, I had the honour to read a short paper before this Society entitled,† "On a simple Method of using an insignificant Fraction of the Main-Current produced by a Dynamo-Electric Machine for Telegraphic Purposes."

In the present paper, I wish to record some more experiments on the same subject. As stated in my former paper, the dynamo-electric machine, during this first experiment, was placed at the store-yard, and was driven by the steam engine of that place. The telegraph current was conveyed to the Calcutta Telegraph Office by the store-yard line, which is about 4 miles in length. This first trial proved so successful that I ventured to propose a larger trial to supply *all* the lines entering the Calcutta Telegraph Office with signalling currents derived in this manner. But I could not then execute the new trial, as in the first place there were no proper driving arrangements at the store-yard (the erection of these would have cost money), and in the second place the dynamo-electric machine at my disposal had, by an accident, been temporarily spoiled. It was thought advisable, therefore, to postpone the suggested trial on a larger scale until the electric light arrangements at Howrah‡ should be completed, when an easy opportunity would offer itself for trying different dynamo-electric machines for the purpose. Besides, telegraph lines being already up between the Howrah Railway Station and the Calcutta Telegraph Office, no additional expense would need to be incurred.

New trial on a larger scale.—The preliminary trial was instituted on the 28th August, the final one on Sunday the 29th August 1880.

In the accompanying diagram, *M* is the dynamo-electric machine which produces the main current to be made use of for any required purpose; the negative pole of the dynamo-electric machine is connected

* The results given in this paper are taken from my report submitted to the Director General of Telegraphs in India on the 7th September 1880.

† J. A. S. B., Vol. xlix, part ii, 1880, and Phil. Mag. No. 52. Suppl., December 1879.

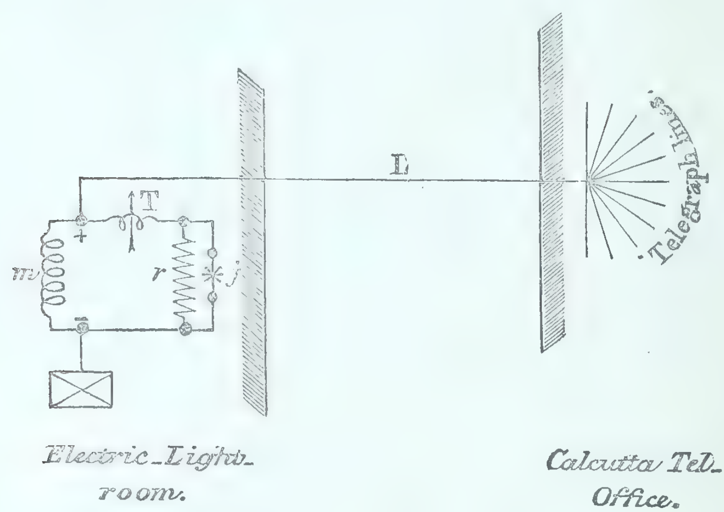
‡ Mr. Bradford Leslie, Agent of the East Indian Railway Company, gave me permission to use the electric light arrangements at Howrah for the purpose. He also kindly permitted the use of the telegraph line connecting his office at Calcutta with the Railway Station at Howrah. This line was required to give orders during the experiment.

permanently to earth. The earth consists of 3 copper plates* joined parallel and offering a parallel resistance of 1·67 ohms.†

T is a tangent galvanometer for measuring the main current. In this case it was the tangent galvanometer employed in my electric light experiments in London in 1878. The resistance of the copper ring of this instrument is *nil*. Taking the late Mr. Brough's value for H, the horizontal component of the Earth's magnetic intensity at Calcutta to be H = 0·37158 dynes, the formula for calculating the currents c from the deflections observed by this tangent galvanometer, is :—

$$c = 47330 \text{ tang } \alpha \text{ (milli-oersted).}$$

r is a coil of iron wire (No. 24 i. w. g., 0·21″ diameter) offering a resistance of 1·517 ohms at 85° F. The wire is coiled on a large wooden drum and serves as the constant resistance by which from time to time the efficiency of the dynamo-electric machines at Howrah can be gauged.



J represents an electric light, in this case produced by a large Serrin-lamp.

In the following experiments, either *r* or *J* was used as the external resistance for closing the poles of the dynamo-electric machine to produce the *main* current ; but *never* the *two* joined parallel.

L is the telegraph line from the dynamo-electric machine to the Calcutta Telegraph Office. This line is 1·75 miles in length and consists, from the electric light room to the Howrah Railway Station, of Hooper's india-rubber cable core, from the Howrah Station to the Kirk, of No. 6

* The three single earths measured gave : 7·7, 3·1, and 6·9 B. A. U.

† The dimensions are 4′ × 2′ and $\frac{1}{16}$″.

i. w. g., and thence to the Calcutta Telegraph Office it is American compound wire of the same resistance as iron wire of No. 27 i. w. g.

At the Calcutta Telegraph Office, the *battery wire** could at a moment's notice be connected with the key of each instrument, after throwing off the copper of the signalling battery in ordinary use. The telegraph lines terminating at the Calcutta Office were therefore all connected *parallel* to the battery wire, as is indicated in the foregoing diagram.

In order to enable me to directly compare the signalling current sent into the lines by batteries and by a dynamo-electric machine, each line is as tested for *sent current* at Calcutta, and for *received current* at the out-station.

Preliminary trial on 28th August 1880.—The line used for tapping the signalling current was No. 5, Calcutta to Allahabad, 577 miles in length, worked *direct* and having a real conduction resistance of about 3075 ohms. (taken from the August 1880 tests). The resistance of the relay at Allahabad equals 492 ohms.

1st Experiment.—This consisted in taking the *sent current* at *Calcutta* and *the received current at Allahabad* as produced by a battery of 60 minotti-cells connected up in series. This is the usual signalling battery during the monsoon.

2nd Experiment.—The main current in this experiment was produced by dynamo-electric machine A† through the resistance r. The resistance in circuit was not measured, but may be taken to be as follows :—

	$m = 0{\cdot}652$	ohms at 85° F.	internal.
	$r = 1{\cdot}517$		$= 1{\cdot}543$ external.
Leading wire to tangent galv.	$l = 0{\cdot}026$		
Total,	$2{\cdot}195$	ohms.	

The main current gave a mean deflection of $37{\cdot}9°$; $\frac{\text{max.}}{\text{min.}} = \frac{39}{36{\cdot}2}$; mean speed of engine 60·3 revolutions per minute; $\frac{\text{max.}}{\text{min.}} = \frac{62}{58{\cdot}5}$. The variation of the current corresponds with the variation of the speed.

3rd Experiment.—The main current in this experiment was produced by dynamo-electric machine E.‡ through the resistance r. This experi-

* The Telegraph line conveying the current produced by the dynamo-electric machine to the Telegraph Office may be called most appropriately the *battery wire.*

† This is a Siemens' dynamo-electric machine called *medium size* (see my *précis* of report on the electric light experiments in London).

‡ This is a Siemens' medium machine altered according to my specification (See *précis* of report on the electric light experiments in London).

ment was made in order to see whether A or E machine would suit the circumstances best.

The resistance in circuit was not measured, but may be taken to be the same as given for A. The main current gave a mean deflection of $30{\cdot}6°$; $\frac{\text{max.}}{\text{min.}} = \frac{33{\cdot}7}{27{\cdot}0}$; mean speed of engine = 59·9 revolutions per minute; $\frac{\text{max.}}{\text{min.}} = \frac{66}{54}$. The variation of the current corresponds with that of the speed.

The results of the preliminary trial are given in the following table :—

No. of Experiment.	Mode of producing the current.	Speed of engine per minute.		Mean speed per minute of dynamo-electric machine.	Mean of main current in milli-oersteds.	Current in milli-oersteds.	
		Mean.	$\frac{\text{Max.}}{\text{Min.}}$			Sent at Calcutta.	Received at Allahabad
1	60 Minotti	...	...	...	9·8	9·8	5·1
2	Dyn. el. machine A.	$60{\cdot}37^{*}$	$\frac{62^{1}}{58{\cdot}5^{1}}$	783	36,846	14·5	7·7
3	Dyn. el. machine E.	$59{\cdot}9^{6}$	$\frac{66^{1}}{54^{1}}$	641	27,991	9·4	6·6

The three experiments were made in the order given. Nos. 2 and 3 were made from 11 to 11·44 hours, during which time messages were sent. The insulation of the battery wire L was variable from 71,000 to 95,000 ohms absolute.

From Experiments 2 and 3, it will be seen that A machine produces a larger main current than E, which is due to the higher speed of A; further, that the *sent current* tapped from the main current of A is larger than the *sent current* tapped from that of E, just as it ought to be. In fact, if the line during the two experiments had kept constant, and if also r had kept constant (r increases considerably by heating), the proportion of the two *main currents* would have been the same as that of the two sent currents, and this is very nearly the case.† No. 3 Experiment with E machine gives about the same result as No. 1 Experiment with battery. To produce the

* The small numbers in the form of exponents mean the number of observations made.

† $\frac{A}{E}$ main currents = 1·32.

$\frac{A}{E}$ sent currents = 1·55.

main current by A is therefore more advantageous than to produce it by E. Hence I employed A in the final trial.

The final trial on Sunday 29th August 1880.—The battery wire, before the trial began, was tested for insulation, and gave an absolute insulation greater than 1 Ω ohm. The main current, as already mentioned, was produced by dynamo-electric machine A; *i. e.*, from 8·45 to 11·5 hours through the wire coil of resistance *r*, and from 11·5 to 11·32 hours through the arc of an electric lamp producing the light J. The light of the lamp was not measured, but may have been equal to about 6,000 standard candles.* The first line was connected to the battery wire at 8·45 hours; the last line at 10·53 hours. The whole trial was completed at 11·32 hours.

The change from *r* to lamp (J) was made in so short a time that none of the out-stations noticed it. Messages were sent and received in the usual regular style.

Mr. C. B. P. Gordon, the Superintendent of the Bengal Division, attended at the Signal Office.

At the beginning of the experiments, the resistances in circuit were measured.

Internal resistance of dynamo-electric machine A	m = 0·652	internal	ohms at 85° F.
Wire coil	r = 1·517	1·543 external	
Leading wire to tangent galvanometer	l = 0·026		

After the experiments were over, these resistances were not measured again; however, on account of the very considerable heating by the strong main current, they must, we know, *all* have increased considerably.

When *r* closed the poles of the dynamo-electric machine (8·45 to 11·5 hours) the mean speed of the engine was 60^{13} revolutions per minute; $\frac{\text{max.}}{\text{min.}} = \frac{64'}{56'}$; while the mean deflection of the main-current was $37{\cdot}87^{68}$; $\frac{\text{max.}}{\text{min.}} = \frac{40{\cdot}25^{1}}{35{\cdot}0^{1}}$.

When the lamp was in circuit (from 11·5 to 11·32 hours), the mean speed of the engine was again 60^{13}; $\frac{\text{max.}}{\text{min.}} = \frac{61}{59}$; while the mean deflection of the main-current was 44^{17}, $\frac{\text{max.}}{\text{min.}} = \frac{46^{2}}{42^{1}}$.

In the following table all the results are given :—

* When measured under 45° with the horizon.

Table shewing the Sent and Received Currents and other particulars.

1	2	3	4	5	6	7	8
No. of Experiment.	Number and name of line and length in miles.	Real conduction resistance of line in b. a. u.	Resistance of Relay at receiving station in b. a. u.	Currents in milli-oersteds. Sent at Calcutta.	Currents in milli-oersteds. Received at out-station.	Mode of producing the currents.	Remarks.
I	No. 1 Jubbulpore 738	4,412	905	6·18 9·81 5·89	4·00 7·60 4·45	100 cells Dyn.-el. m. A 100 cells	The several lines were connected to the battery wire in the order given in this table. The first line, Jubbulpore No. 1, was connected at 8·45 hours; the last line No. 3, Agra, at 10·53 hours. Before the actual experiments began, *i. e.*, before 8·45 hours, all the lines were tested for *sent currents* at Calcutta, and *received currents* at the outstations, when the usual signalling battery was on. Directly after each line had been connected to the battery wire of the dynamo - electric machine, the *sent currents* at Calcutta and the *received currents* at outstations were taken.
II	No. 4 Jubbulpore 803	5,795	406	7·07 10·23 7·41	3·60 4·71 3·50	60 cells Dyn.-el. m. A 60 cells	
III	No. 5 Allahabad 577	3,075	492	9·81 13·79 9·41	6.50 8·57 5·08	60 cells Dyn.-el. m. A 60 cells	
IV	No. 6 Sahibgunge 225	2,000	506	7·14 21·65 6·63	4·09 11·40 4·23	20 cells Dyn.-el. m. A 20 cells	
V	No. 7 Cuttack 400	2,800	953	6·63 11·00 6·63	3·00 6·00 3·38	35 cells Dyn.-el. m. A 35 cells	
VI	No. 8 Coconada 800	7,000	3,711	4·00 8·15 4·00	3·60 7·20 2·01	119 cells Dyn.-el. m. A 119 cells	
VII	No. 9 Akyab 560	3,460	3,470	7·69 6·77 6·18	4·00 3·90 5·35	120 cells Dyn.-el. m. A 120 cells	
VIII	No. 11 Dhubri	...	1,427	6·40 11·78 6·42	5·00 11·45 5·73	40 cells Dyn.-el. m. A 40 cells	
IX	No. 10 Akyab 561	4,400	...	15·39 15·39 17·43	3·10 3 90 3·30	80 cells Dyn.-el. m. A 80 cells	
X	No. 2 Agra 915	6,700	829	15·39 7·14 14·52	6·40 3·90 6·15	195 cells Dyn.-el. m. A 195 cells	
XI	No. 3 Agra 850	5,800	1,959	13·54 13·38 9·41	3·25 3·10 4 14	100 cells Dyn.-el. m. A 100 cells.	

After the dynamo-current was stopped at 11·32 hours, and the batteries had been connected up again, the *sent currents* at Calcutta and the *received currents* at outstations were again ascertained Hence columns 5 and 6 contain 3 readings of *sent* and *received currents* for each line; first, with battery, secondly, with the dynamo-electric machine, and, thirdly, with the battery again. All the readings of the currents tapped from the main current of the dynamo-electric machine were taken between 8·45 and 10·53 hours, when the iron wire coil of resistance r was connected to the poles of the dynamo-electric machine. From 11·5 to 11·32 hours, when the lamp was substituted for r, no current readings at Calcutta and the outstations were taken.

The main current of the dynamo-electric machine, when r was in circuit, was 36,801 m. ö; when the lamp was in circuit, 45,706 m. ö.* From this it does not follow, however, that the tapped currents in the second case were larger than in the first, because it would also depend on the resistance offered by the arc, which is not known. The resistance of the arc, as more current was produced with the same speed of the dynamo-electric machine, must naturally have been smaller than $r = 1·517$ b. a. u. (iron wire coil), especially as there is an e. m. f. in the arc opposite to the e. m. f. of the dynamo-electric machine.

To produce 36,801 milli-oersteds through an external resistance of about 1·513 b. a. u., a total energy is consumed by the dynamo-electric machine of about 27,000 Ω ergs per second (representing about 3 h. p. per second).

Conclusions.—These experiments shew that it is perfectly possible and practicable to tap from the main current produced by a dynamo-electric machine *all* the signalling currents required at the Calcutta Telegraph Office. These currents were for the 11 lines connected up = 129·1 m. ö, if all keys were simultaneously and permanently sending. This represents only 0·35 °/₀ of the main current (36,801 m. ö) with r in circuit, and ·28 °/₀ of the main current (45,706 m. ö) with lamp in circuit. Further it will be clear that such a small variation of the main-current could not influence the regularity of any work done by that main-current.

Further, it will be seen that in all the experiments the sent currents tapped from the main current of the dynamo-electric machine were considerably larger than when produced by the large batteries at present in use. Experiments IX and X only form an exception. However, I think these exceptions are in both cases due to errors of observation, because the battery readings in Experiment IX do not all agree. The dynamo-current readings in No. X must be wrong, because in No. XI, for a total circuit resistance of 7759 units, the sent current is 13·38 m. ö,

* Calcutta by the formula: $e = 47330$ to (m. 0″).

while in No. X, for a total circuit resistance of 65·29, the sent current is only 7·14. The error of observation is therefore obvious.

That with such strong received currents as are produced when the dynamo-electric machine is used, the lines should work well, is not to be wondered at. But it was also confirmed by the outstations having to adjust their relays much more unsensitively.

Supposing now that we had useful work *day* and *night* for the strong main current, and that on the whole the new method could be always depended upon, I believe these experiments have proved that the signalling currents required in telegraph stations could be had for *nothing*, and that the method would be quite practicable.

The useful work for the main current at night would most conveniently take the shape of an electric light to illuminate very efficiently the Signal Office. The electric light, besides being more powerful, would possess the additional advantage of being produced by at least 50 times less heat than if the same light were obtained by combustion. This is no doubt a great advantage in a hot climate. During the daytime, I would use the main current for pulling punkhas, lifting messages, or, more generally, for working a pneumatic system of sending and receiving messages, &c., &c. If Calcutta had the good fortune to possess a colder climate, it might be suggested that the heat developed in the coil of wire should be used for warming rooms. It would then only be necessary to lead the wire along the walls, in a manner similar to that in which hot water pipes often are for heating rooms; the electric method being only far more economical. The heat given up by the wire, after dynamic equilibrium of the system has been established, is quite regular, and the method is obviously exceedingly clean and very convenient for domestic purposes. The wire attained its constant temperature of 93° C. after the current had acted for about half an hour, the air of the room having a temperature of 30° C.

The heat given out by the wire is by no means small. For instance, in our case, the average current working through a resistance $r = 1{\cdot}543$ b. a. u. was 36801 milli-oersteds. This represents work done at a rate of 20473 Ω ergs per second, and supposing the wire has obtained its constant temperature, this whole energy is developed into heat emitted by the wire into space at a rate of $\frac{20473}{42} = 488$ gramme-degree-centigrade per second. This is equal to the heat produced by an ordinary German stove consuming 6lbs of coals per hour; supposing that the loss of heat when coals are burnt under a steam-boiler is four times as great as when they are burnt in a German stove. It appears, therefore, that the heat developed by the wire would be sufficient to keep a moderately sized and ordinarily ventilated room at a comfortable temperature even when situated in the highest latitudes.